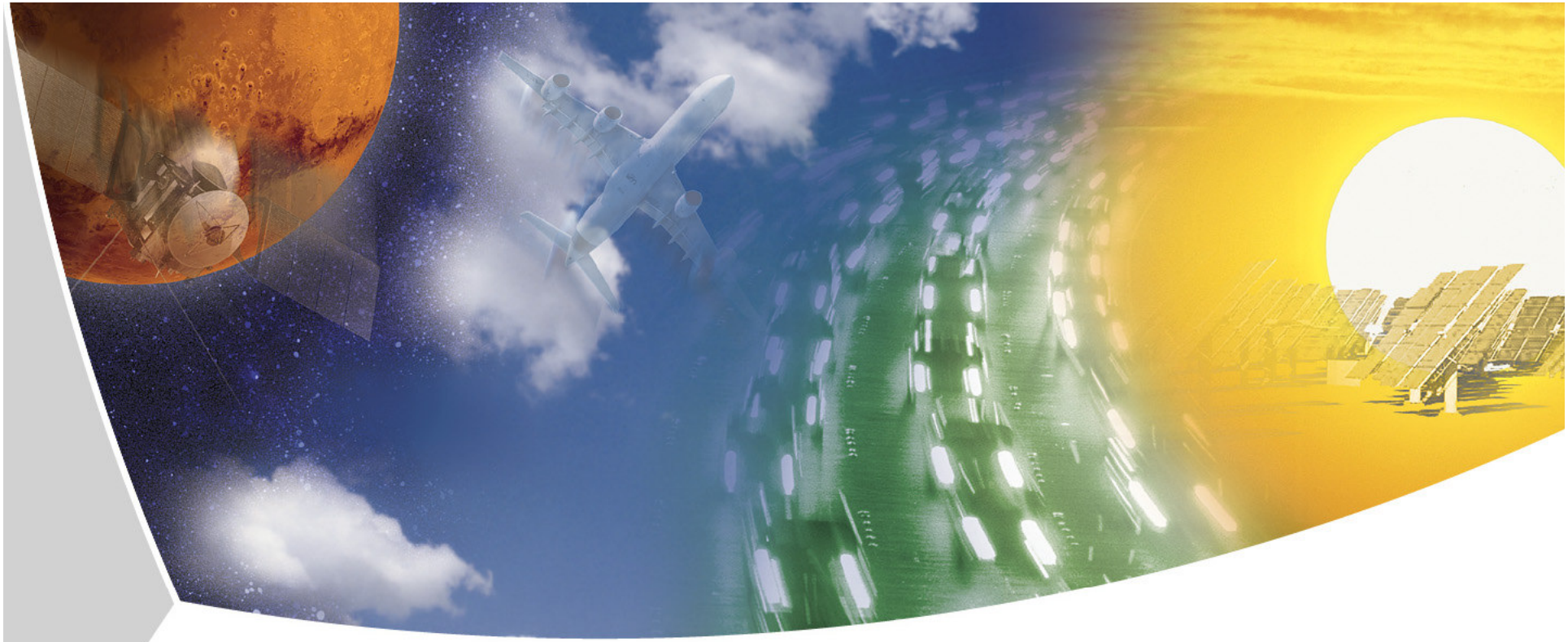


Forest Parameter Estimation in Tropical Forests by means of Pol-InSAR: Evaluation of the INDREX II Campaign

Florian Kugler, K.P. Papathanassiou & Irena Hajnsek

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Agenda

Theory Random Volume over Ground Model

Sungai Wain Test Site

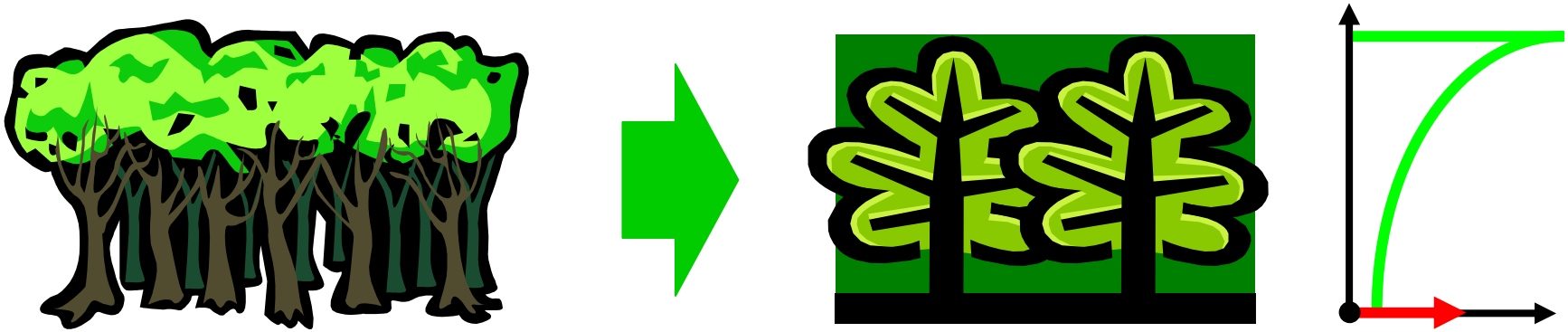
- *Ground Truth*
- *Topography*
- *Inversion Results L Band and P Band*

Mawas Test Site

- *Ground Truth*
- *Inversion Results X Band*

Summary

Random Volume over Ground (RVoG) Scattering Model



Interferometric Coherence:

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$$

Volume Coherence:

$$\tilde{\gamma}_V = \frac{I}{I_0}$$

$$I = \int_0^{h_V} \exp(i\kappa_z z')\exp\left(\frac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'$$

$$I_0 = \int_0^{h_V} \exp\left(\frac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'$$

G/V Ratio: $m(\vec{w}) = \frac{m_G(\vec{w})}{m_V(\vec{w})I_0}$

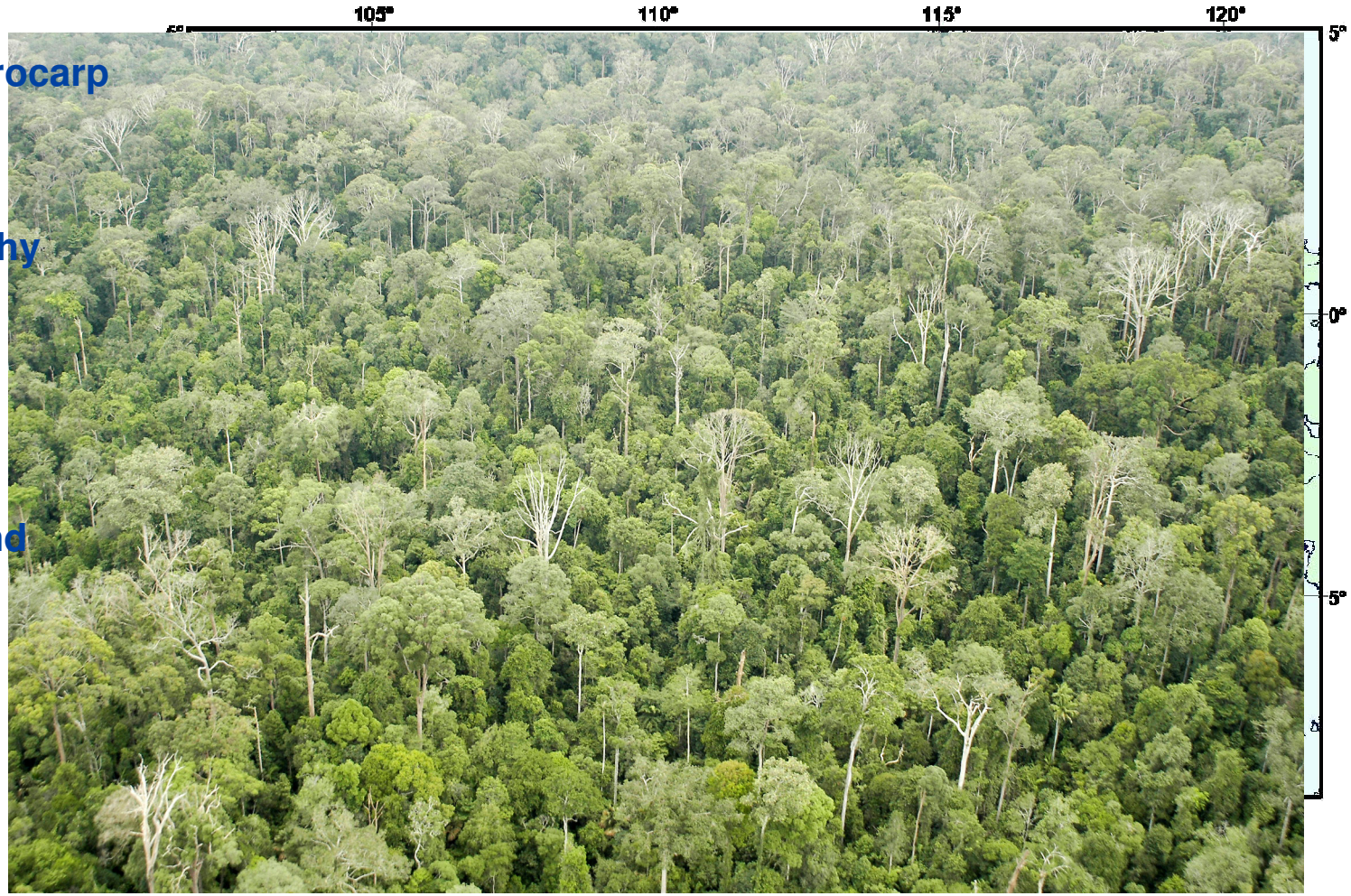
Vertical Wavenumber: $\kappa_z = \frac{\kappa\Delta\theta}{\sin(\theta_0)}$

4 Parameters:

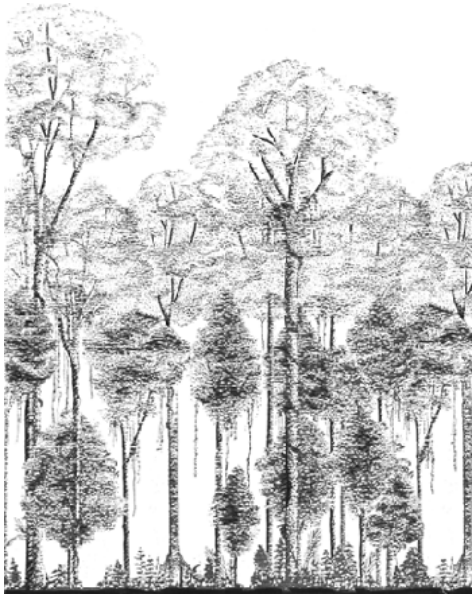
- *Volume height* h_V
- *Extinction* σ
- *Topography* φ_0
- *G/V Ratio* $m(\vec{w})$

Test Site: Sungai Wain

- Lowland Dipterocarp Forest
- Hilly Topography
- Forest Height: 10m – 50m
- Biomass around 100 - 400t/ha
- Closed canopy
- Dense



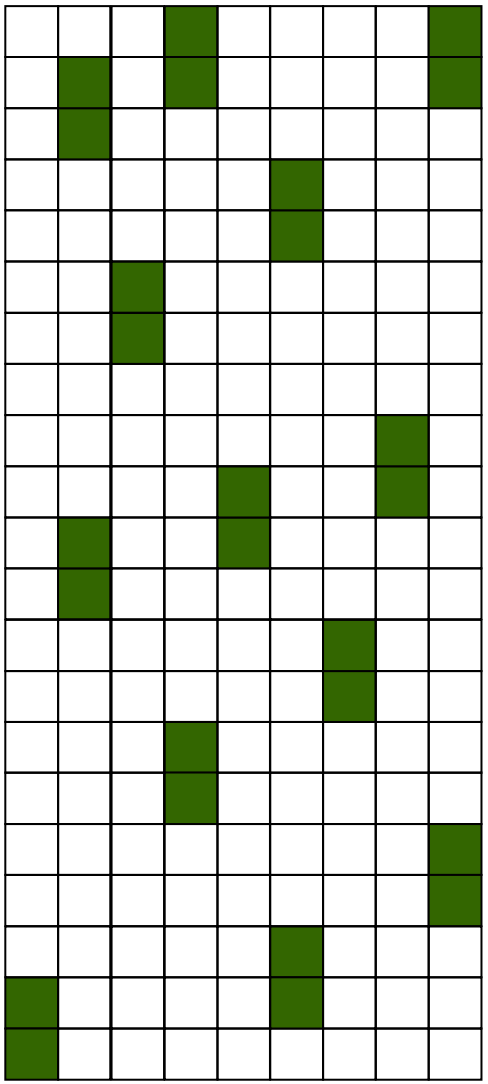
Reference Height Sungai Wain



Plot design: 216m x 672m

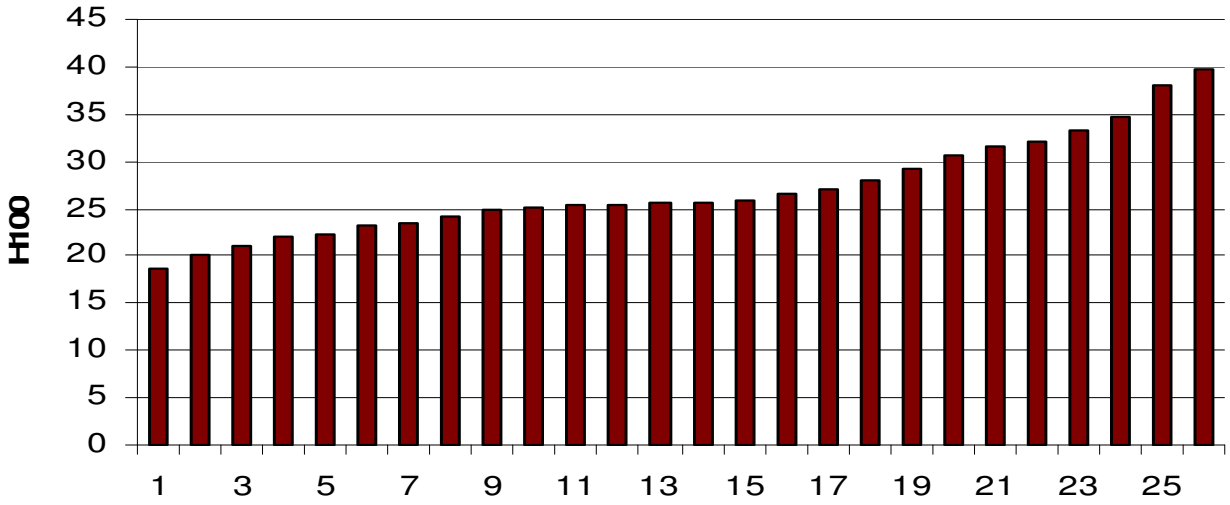
5.4 ha plot

Suplots: 24m x 32m



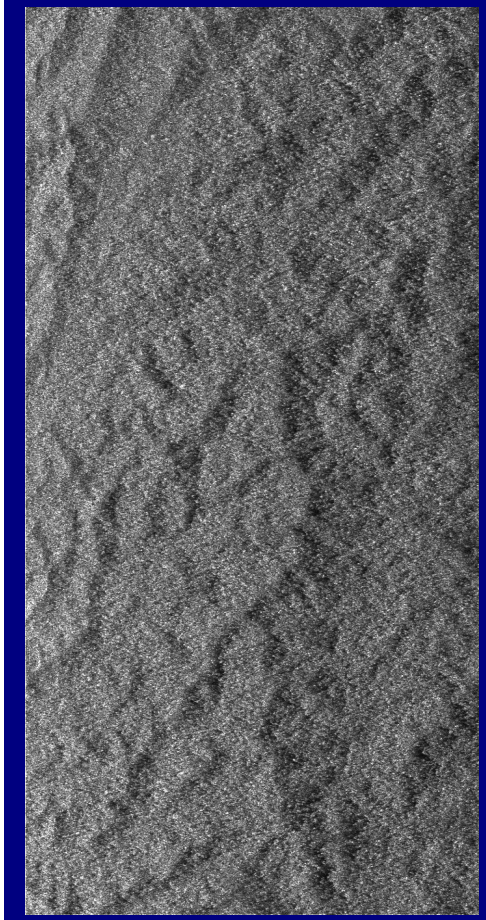
Top Height H100 for each Subplot

Mean height of subplots: 27m

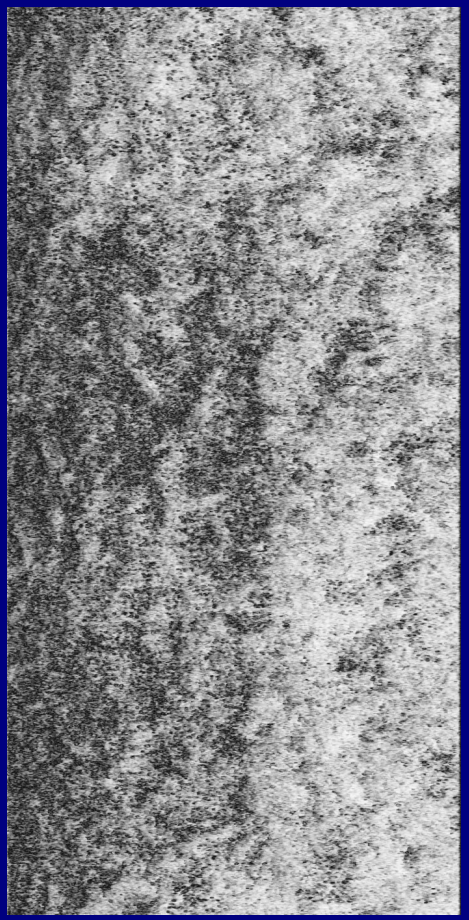


Radar Data Sungai Wain

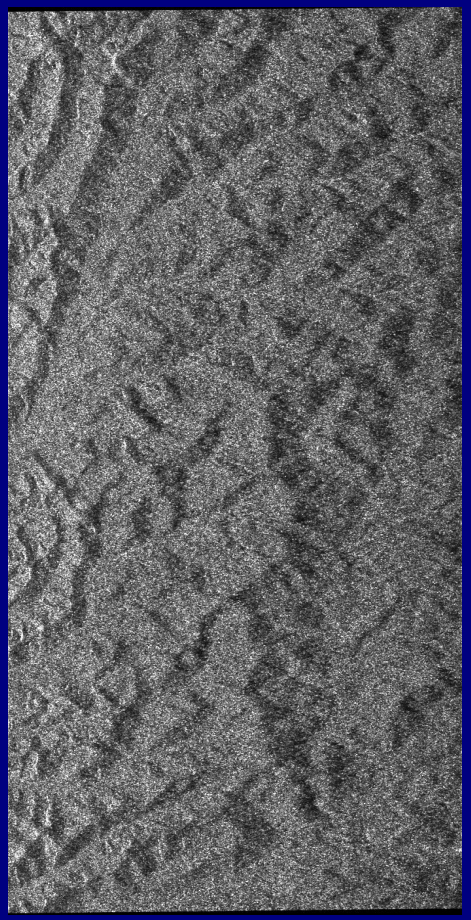
L Band **P Band**



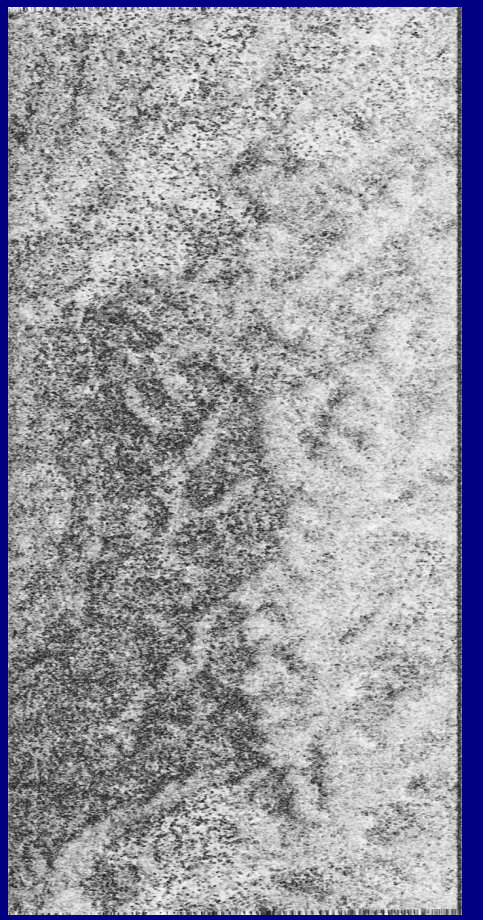
Amplitude



Coherence



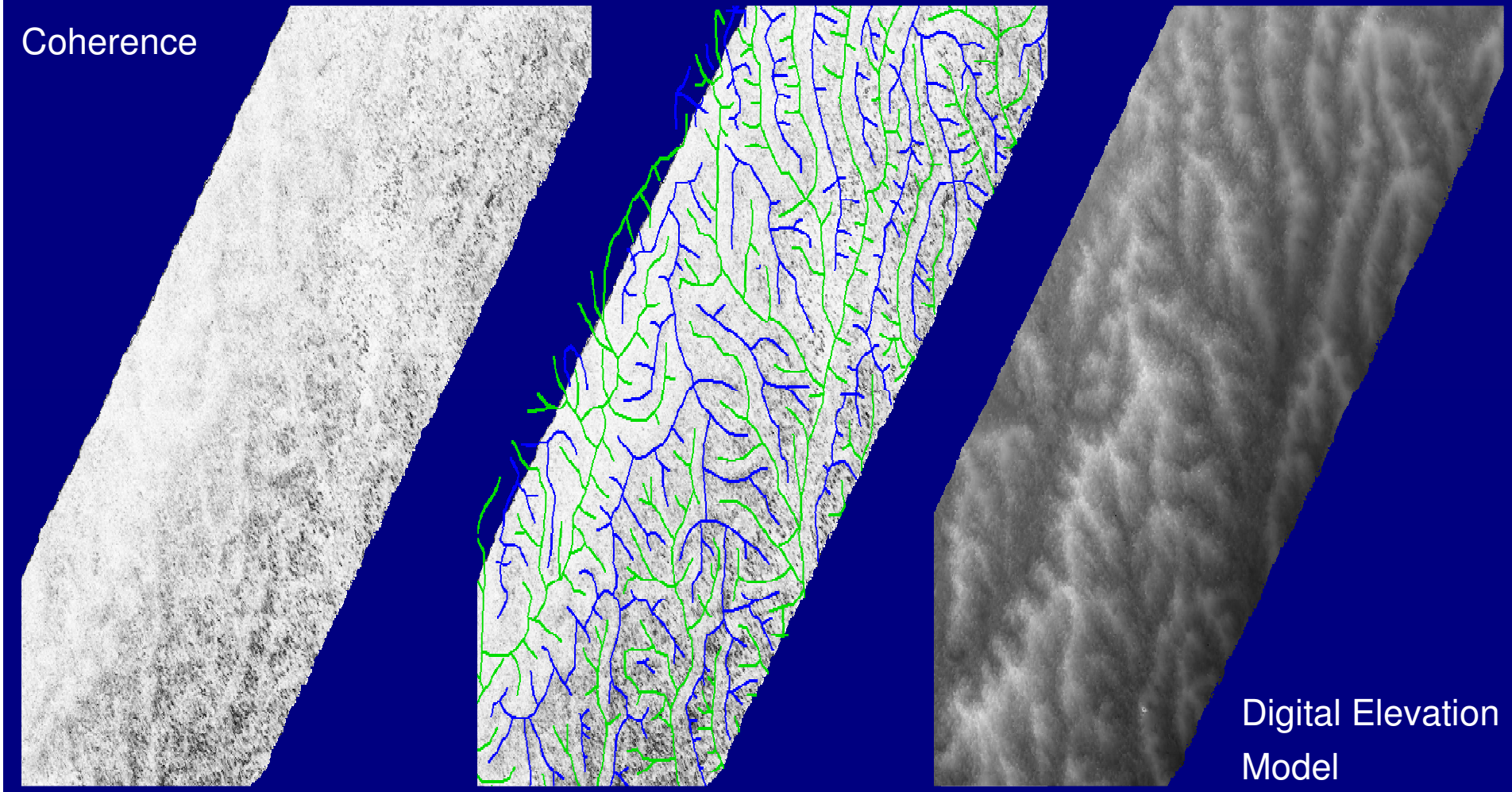
Amplitude



Coherence

Topographic Dependency of InSAR Coherence (P band)

Coherence



Digital Elevation Model

Topo Lines over Coherence: ridge (blue), valley (green)

The Effect of Topography on InSAR Coherence

Interferometric Coherence:

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\,\frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$$

$$m(\vec{w}) = \frac{m_G(\vec{w})}{m_V(\vec{w})I_0}$$

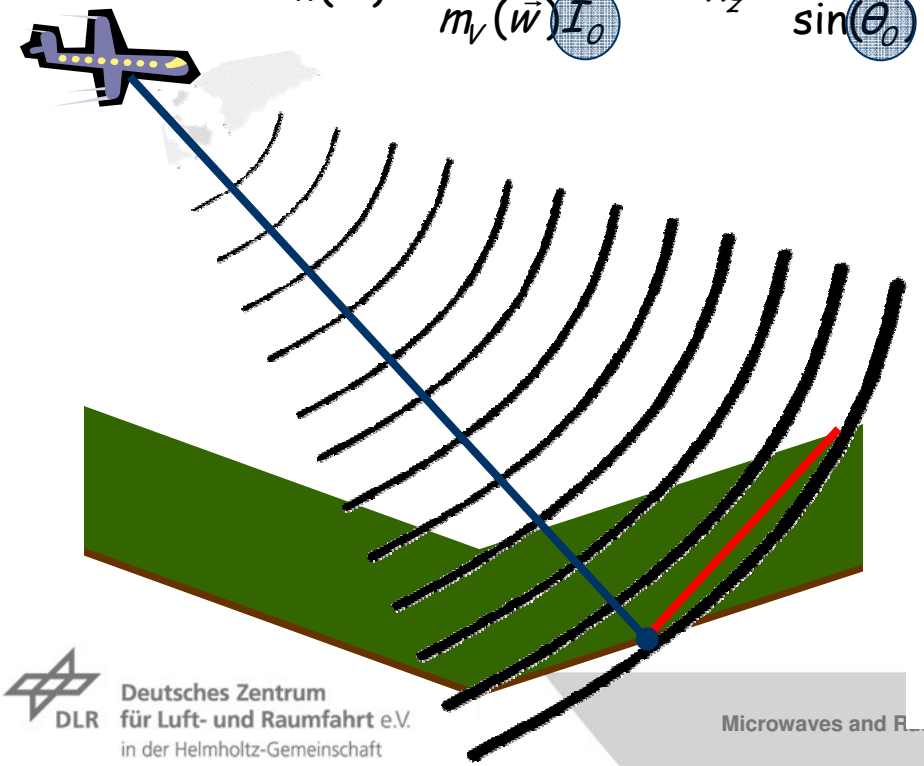
Volume Coherence:

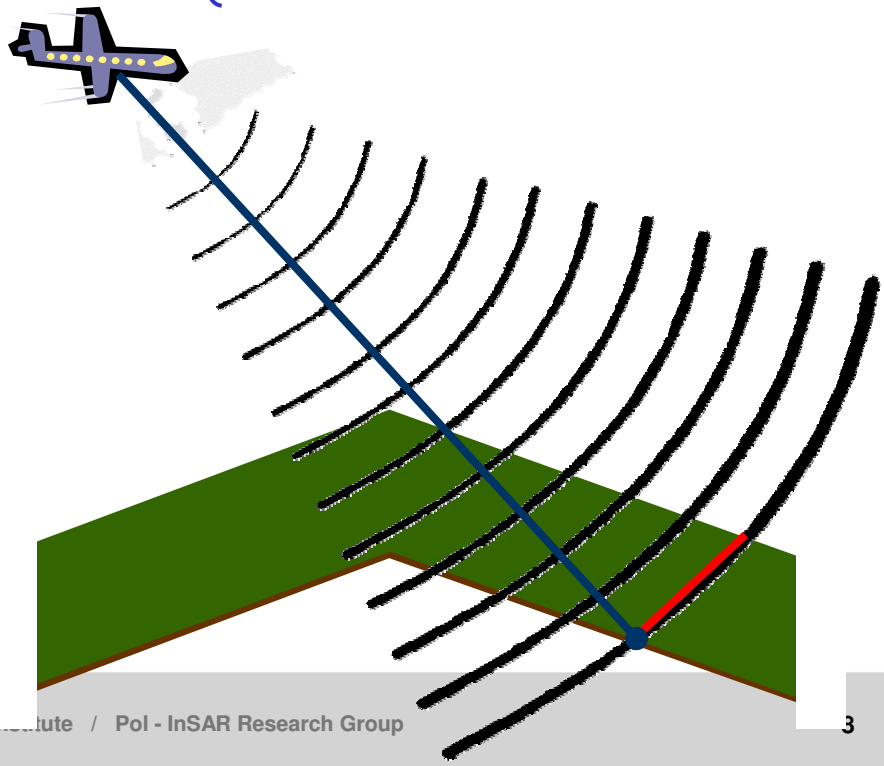
$$\tilde{\gamma}_V = \frac{I}{I_0}$$

$$I = \int_0^{h_V} \exp(i\kappa_z z')\exp\left(\frac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'$$

$$I_0 = \int_0^{h_V} \exp\left(\frac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'$$

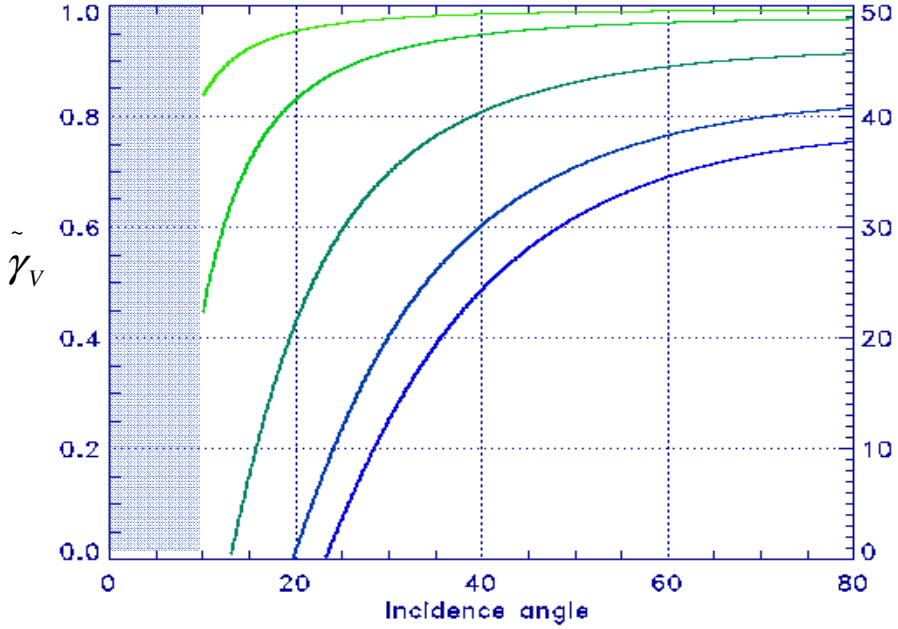
$$\kappa_z = \frac{\kappa\Delta\theta}{\sin(\theta_0)}$$



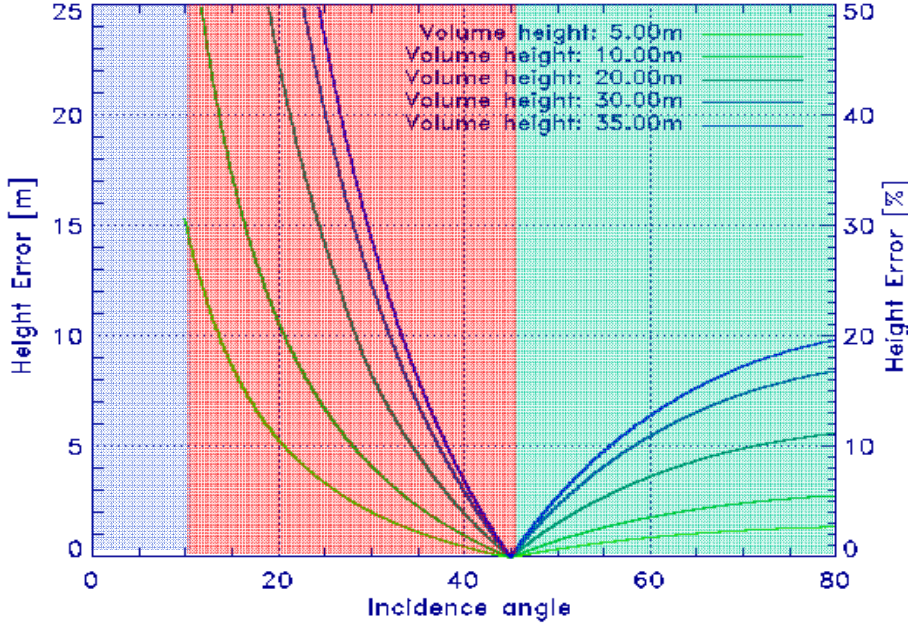


Topography Induced Height Error

Change of Volume Coherence



$\tilde{\gamma}_V$



Modelling Parameters: Extinction: 0dB/m

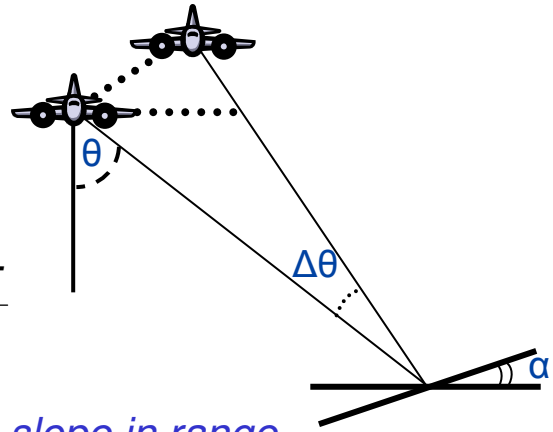
Incidence angle: 45°

Vertical Wavenumber: 0.1

Terrain Compensation: Vertical Wavenumber

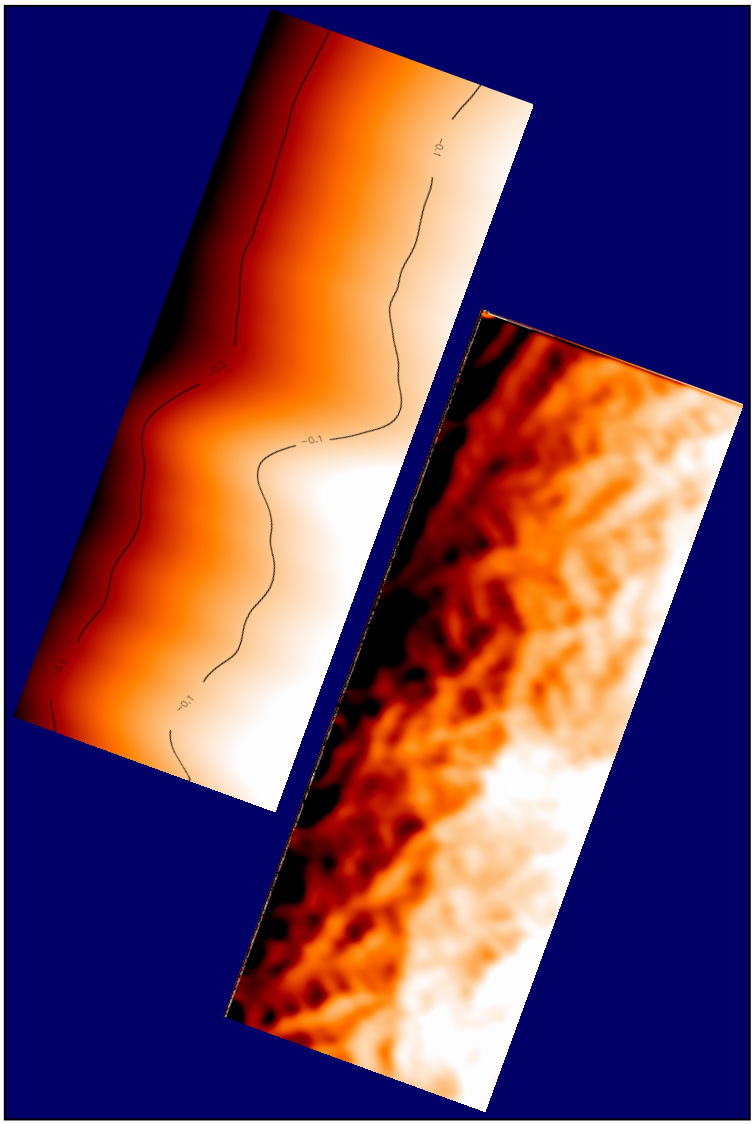
Terrain Adaptive Vertical Wave-Number:

$$k_z = \frac{k\Delta\theta}{\sin(\theta - \alpha)} \qquad k = \frac{4\pi}{\lambda}$$

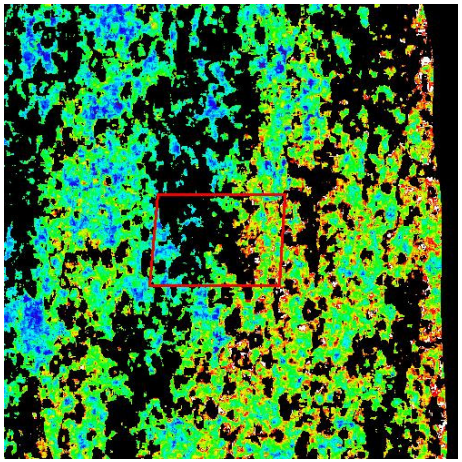


where α is the terrain slope in range.

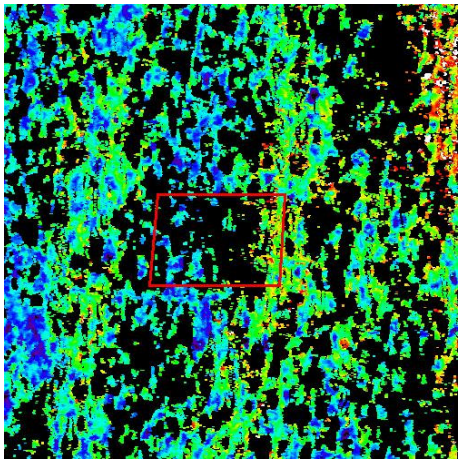
α is estimated from the low-pass filtered X-band DEM (to filter-out the DEM variation due to vegetation).



Validation Sungai Wain Plot

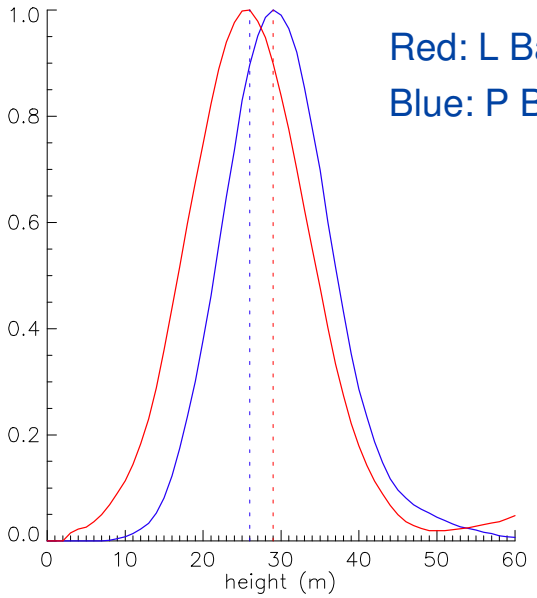


P – Band



L – Band

Radar Heights



Red: L Band

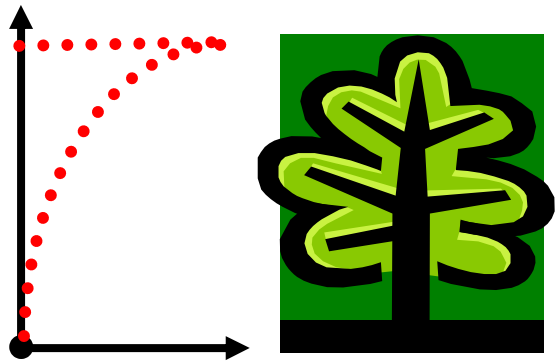
Blue: P Band

Reference Height from Ground Measurements: 27m

L Band Mean: 26m

P Band Mean: 29m

RVoG Inversion at X-band



$$\tilde{\gamma}_1(\vec{w}_1) = \exp(i\varphi_0)\frac{\tilde{\gamma}_V + m_1(\vec{w}_1)}{1 + m_1(\vec{w}_1)}$$

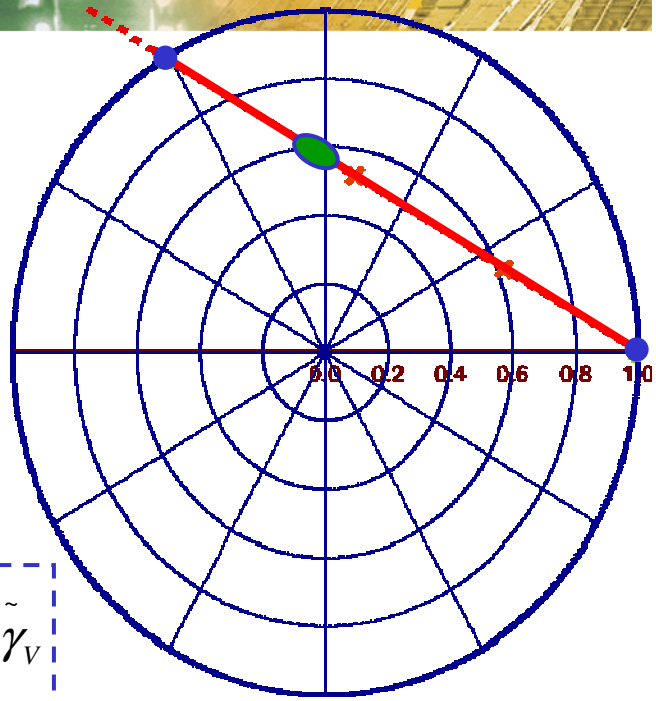
$$\tilde{\gamma}_2(\vec{w}_2) = \exp(i\varphi_0)\frac{\tilde{\gamma}_V + m_2(\vec{w}_2)}{1 + m_2(\vec{w}_2)}$$

$$\tilde{\gamma}_3(\vec{w}_3) = \exp(i\varphi_0)\frac{\tilde{\gamma}_V + m_3(\vec{w}_3)}{1 + m_3(\vec{w}_3)}$$

Assumption:

$$m_1(\vec{w}_1) = m_2(\vec{w}_2) = m_3(\vec{w}_3) = 0$$

$$\tilde{\gamma}_1(\vec{w}_1) \approx \tilde{\gamma}_2(\vec{w}_2) \approx \tilde{\gamma}_3(\vec{w}_3) \approx \exp(i\phi_0)\,\tilde{\gamma}_V$$



$$\tilde{\gamma}_V(h_V, \sigma \mid \kappa_z) = \frac{I}{I_0}$$

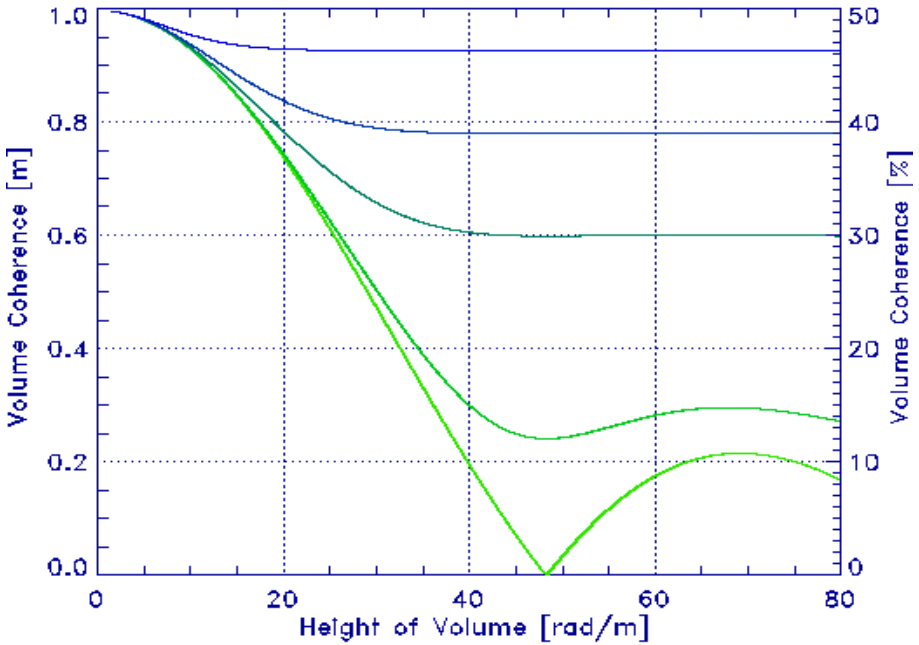
$$I = \int_0^{h_V} \exp(i\kappa_z z')\exp\left(\frac{2\,\sigma\, z'}{\cos\theta_0}\right)dz'$$

$$I_0 = \int_0^{h_V} \exp\left(\frac{2\,\sigma\, z'}{\cos\theta_0}\right)dz'$$

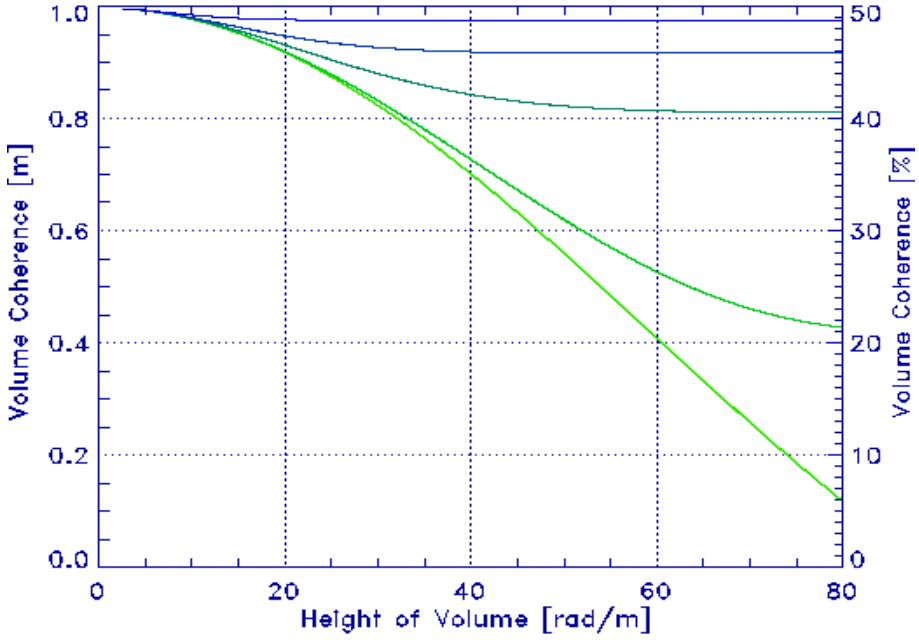
$$|\tilde{\gamma}_i(\vec{w}_i)| = |\tilde{\gamma}_V(h_V, \sigma \mid \kappa_z)|$$

Underdetermined:
1 Equation for 2 Unknowns

Performance of X-band Inversion for DLR E-SAR



Vertical Wavenumber: 0.13



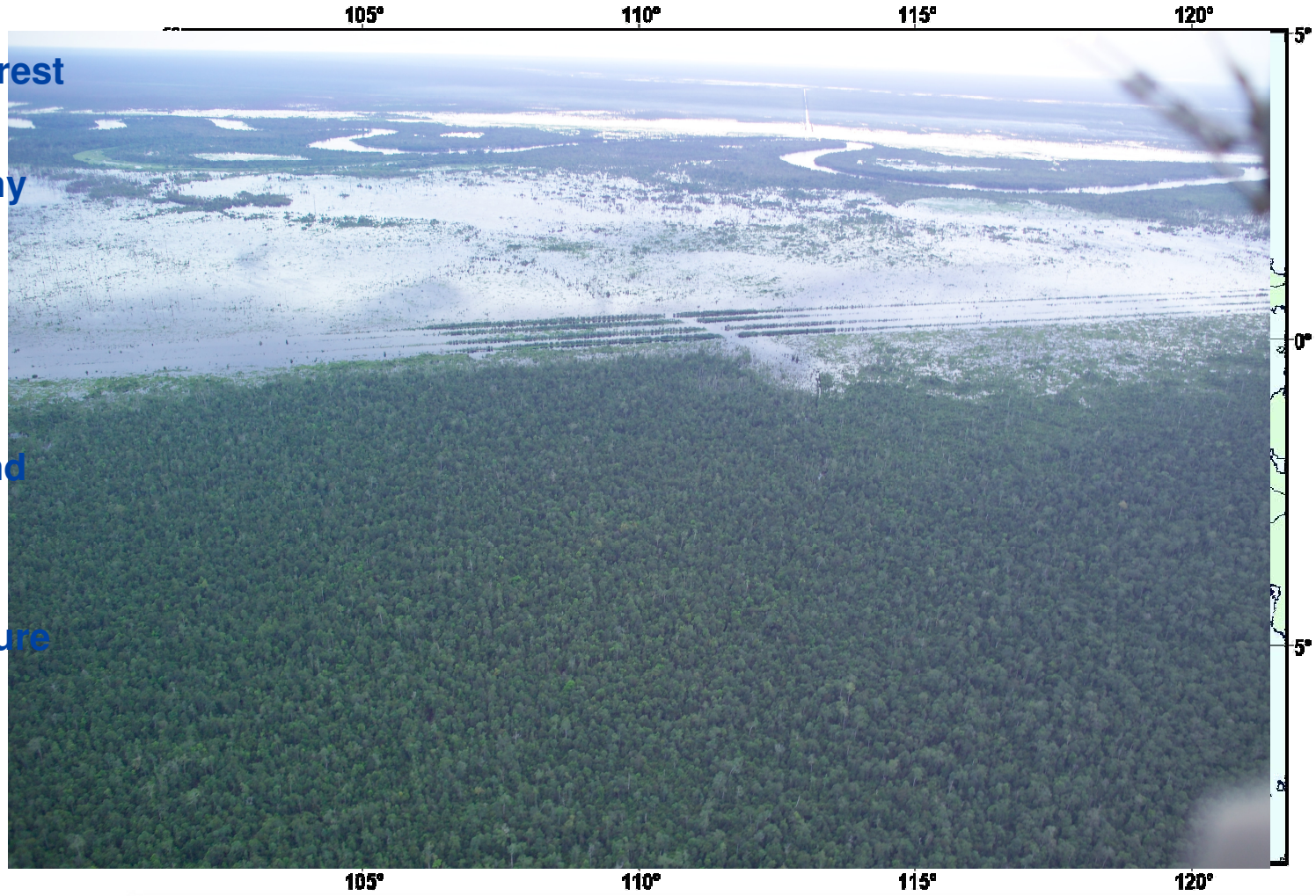
Vertical Wavenumber: 0.07

Extinction:

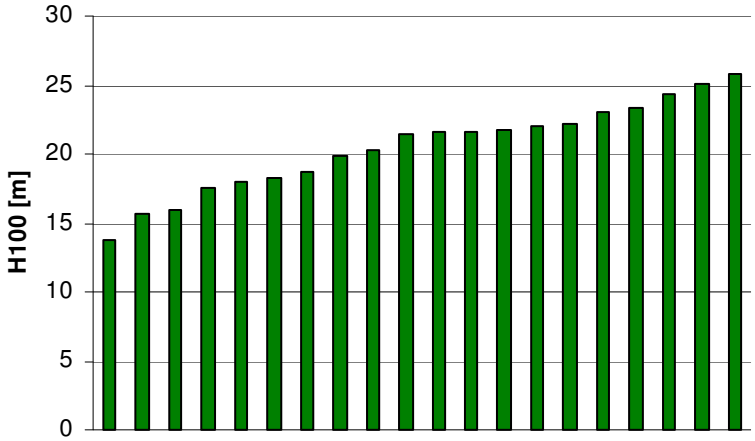
- 0 dB/m
- 0.1 dB/m
- 0.3 dB/m
- 0.5 dB/m
- 1.0 dB/m

Test Site: Mawas

- Peat swamp forest
- Flat Topography
- Forest Height:
  15m – 25m
- Biomass around
  100t/ha
- Uniform structure
- Open canopy



Reference Height Mawas

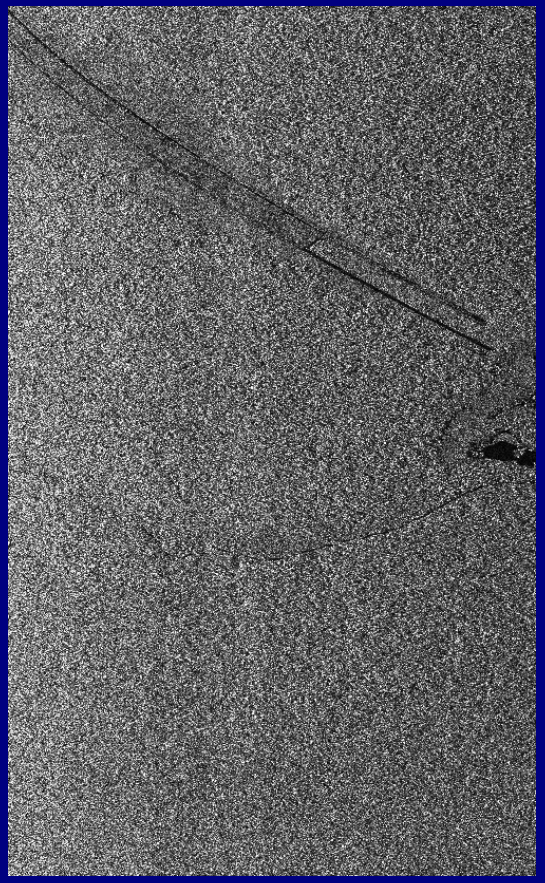


21m 23m

1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

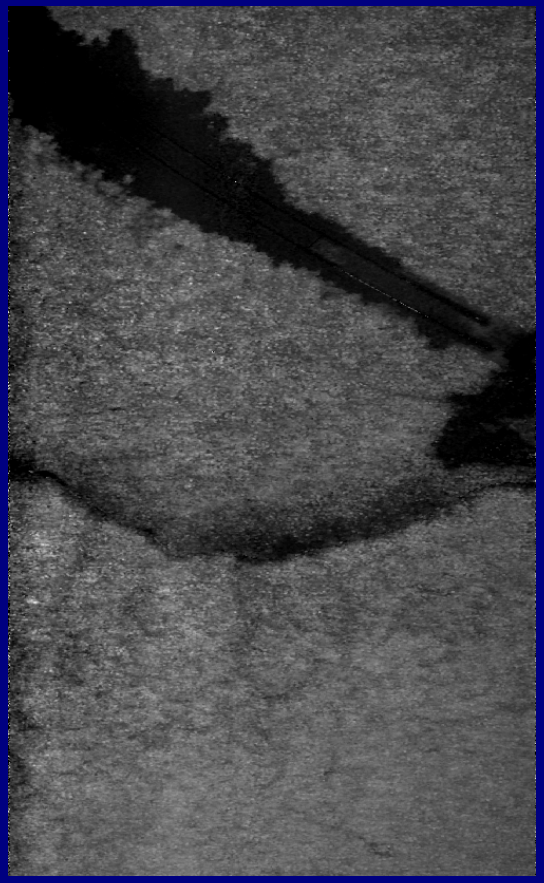
Plot design of Ground truth: 20 squares of 10m x 10m in two Transects

Radar data Mawas X Band



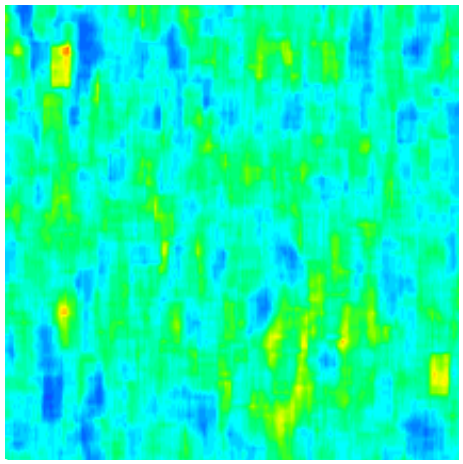
Amplitude

Phase: -π to π

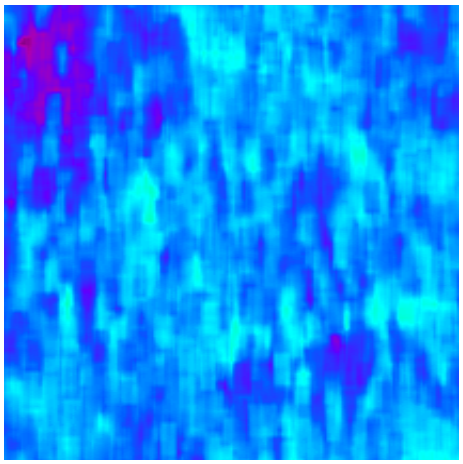


Phase difference: 0 to π

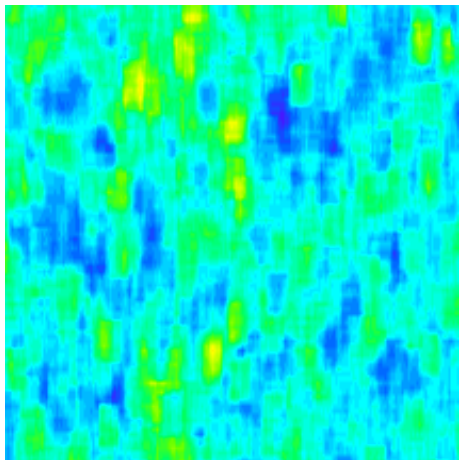
Comparison Phase Center Height vs. Volume Height



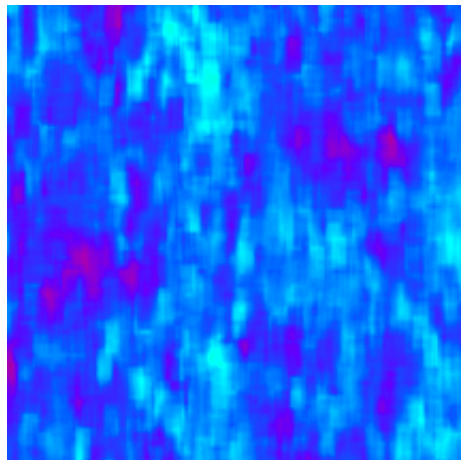
Coherence Height left



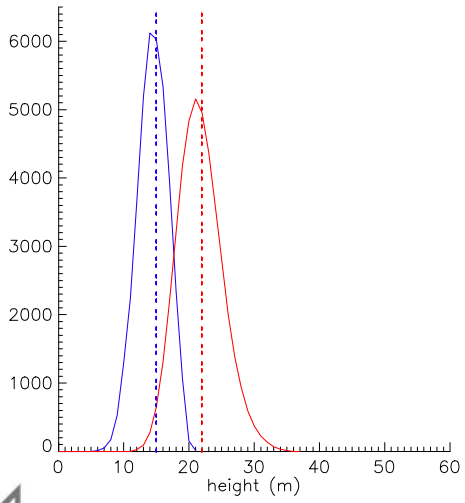
Phase Height left



Coherence Height right



Phase Height right



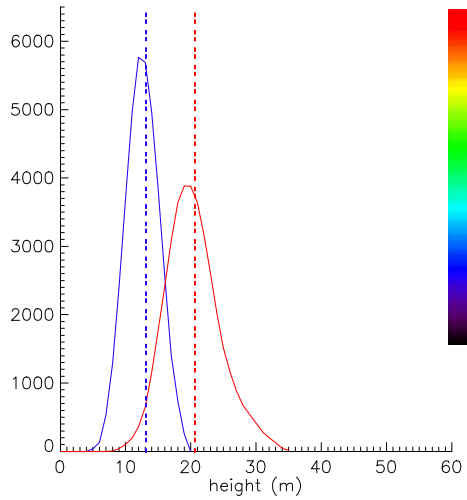
Extinction: 0.1 db/m

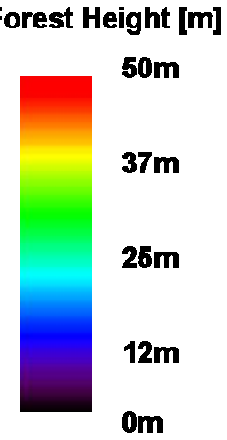
Blue: Phase Height

Red: Coherence Height

Ground measurements:

21m – 23m





Summary

Forest height over tropical rainforest was estimated and successfully validated in L band as well as in P band

Topography effects forest height estimation and has to be compensated

Forest height estimation using X band is possible for certain (sparse) forest conditions (such as the mawas peat swamp forests)

X band Phase Scattering Center is lower than Pol-InSAR forest height

Thank you!